



**“T-Cubed!”**

# T<sup>3</sup> Project Overview for NARI Seedling Technical Seminar

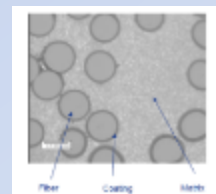
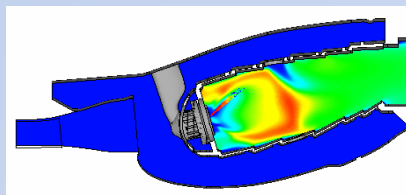
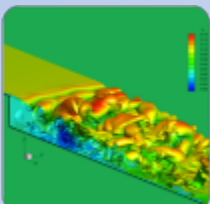
**November 17, 2015**

Mike Rogers, Project Manager (Acting, ARC)

Rob Scott, Deputy Project Manager (LaRC)

Dale Hopkins, Associate Project Manager (Acting, GRC)

Debbie Findley, Business Lead (GRC)



# NASA Aeronautics Program Structure



## Aeronautics Research Mission Directorate

### Mission Programs

### Seedling Program

**Advanced Air  
Vehicles (AAVP)**

**Airspace Operations  
And Safety (AOSP)**

**Integrated Aviation  
Systems (IASP)**

**Transformative Aeronautics  
Concept (TACP)**

**Advanced Air  
Transport Technology  
(AATT)**

**Airspace Technology  
Demonstration  
(ATD)**

**Environmentally  
Responsible  
Aviation  
(ERA)**

**Transformational Tools  
and Technologies  
(T<sup>3</sup>)**

**Revolutionary Vertical  
Lift Technology  
(RVLT)**

**SMART NAS – Testbed  
for Safe Trajectory  
Operations**

**UAS Integration  
in the NAS**

**Convergent Aeronautics  
Solutions  
(CAS)**

**Commercial Supersonic  
Technology  
(CST)**

**Safe Autonomous  
System Operations  
(SASO)**

**Flight Demonstration  
and Capabilities  
(FDC)**

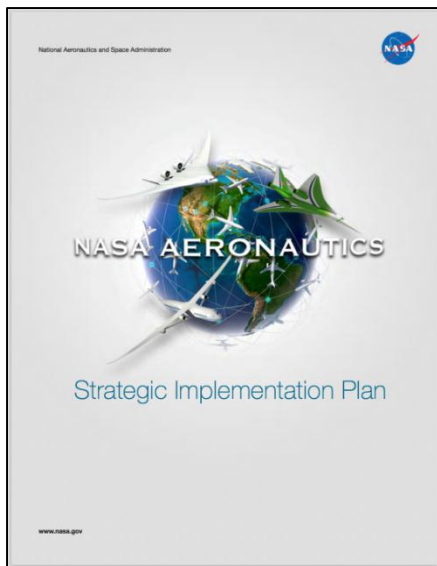
**Leading Edge  
Aeronautics Research  
for NASA  
(LEARN)**

**Advanced Composites  
(ACP)**

**Aeronautics Evaluation  
and Test Capabilities  
(AETC)**



# NASA ARMD SIP and Strategic Thrusts



## Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks



## Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard



## Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance



## Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

**Primary  
areas of  
project  
emphasis**



## Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system



## Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications



T<sup>3</sup> Project can potentially support all 6 thrusts



# Transformational Tools & Technologies (T<sup>3</sup>) Project

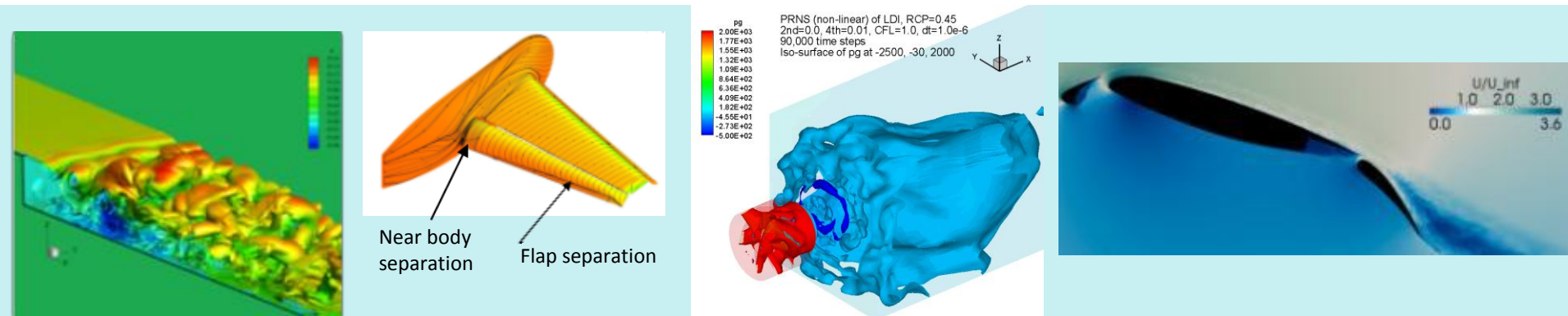
*Enable fast, efficient design & analysis of advanced aviation systems from first principles by developing physics-based tools/methods & cross-cutting technologies, provide new MDAO & systems analysis tools, & support exploratory research with the potential to result in breakthroughs*

## Vision

- Physics-based predictive methods for improved analysis and design
- Leverage improved understanding and discipline integration toward improved future air vehicles

## Scope

- Foundational research and technology for civil air vehicles
- Discipline-based research and system-level integration method development





# Transformational Tools & Technologies (T<sup>3</sup>)

## Project Management Structure



PROJECT LEVEL

**Executive Team:**  
Project Manager – Mike Rogers (Acting, ARC)  
Deputy Project Manager – Rob Scott (LaRC)  
Associate Project Manager – Dale Hopkins (Acting, GRC)

**Project - Center Liaisons:**  
Mike Rogers (ARC)  
Jeff Bauer (AFRC)  
Laura Stokley (GRC)  
Melinda Cagle (LaRC)

Business Lead – Debra Findley (GRC)  
Center Analysts – Cecelia Town (ARC)  
Lisa Logan (AFRC)  
Joe Sessa (GRC)  
Renee' Williams (LaRC)  
NRA Manager – Renee' Williams (LaRC)  
Scheduler – Joyce Moran (GRC)

SUB-PROJECT

**Revolutionary Tools & Methods (RTM)**  
**SPM – Melinda Cagle (LaRC)**  
**Sub-Project Technical Leads:**  
RCA – Mujeeb Malik (LaRC)  
Combustion Modeling – Jeff Moder (GRC)  
MDAO/SA – Jeff Viken (LaRC)  
M&S Modeling – Dale Hopkins (GRC)

Development of revolutionary comprehensive physics-based aeronautics analysis and design capability.  
Philosophically based on Vision 2030 study recommendations.  
**Current Technical Challenge to reduce CFD error by 40% by 2017.**

**Critical Aeronautics Technologies (CAT)**  
**SPM – Laura Stokley (GRC)**  
**Sub-Project Technical Leads:**  
M&S Technologies – Dale Hopkins (GRC)  
iMeasurements – Tom Jones (LaRC)  
Propulsion Controls – Dennis Culley (GRC)  
Flight Controls – Jay Brandon (LaRC) and Joe Pahle (AFRC)  
Combustion Technologies – Jeff Moder (GRC)

Development of critical aeronautics technologies that can enable revolutionary improvement in aircraft system design. Innovative ideas that may lead to patentable results.  
**Current Technical Challenge to develop 2700F-capable engine materials by 2017.**



# Technical Challenges and Research Areas



Revolutionary Tools & Methods	Critical Aeronautics Technologies
RCA - <b>Physics Based Modeling Simulation (TC #1)</b> \$13.3M	
M&S - Modeling, Simulation & Validation (RA) \$896K	M&S - <b>High-Temperature Materials (TC #2)</b> \$4.6M
	M&S - Multifunctional Materials & Structures (RA) \$1.5M
MDAO/System Analysis Tools (eTC) \$5.0M	
Combustion Modeling (eTC) \$3.0M	Combustion Technologies (RA) \$1.7M
	Propulsion Controls (RA) \$1.6M
	Flight Controls: Learn to Fly (RA) \$649K
	Flight Controls: Cooperative Trajectories (RA) \$649K
	Innovative Measurements (eTC) \$3.0M

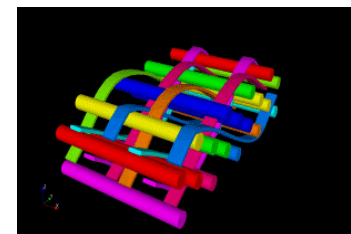
2 TCs, 3 eTCs, 6 RAs = 11 Areas to Cover



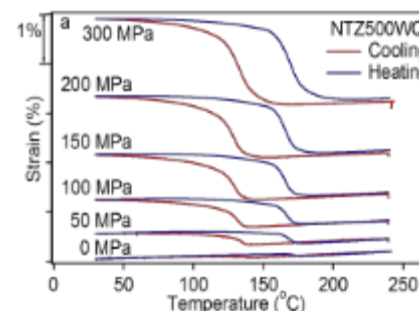
- Develop **high temperature engine materials** and associated design, analysis and life prediction tools to reduce or eliminate turbine cooling requirements and reduce weight
- Develop **multifunctional materials and structural configurations** that reduce weight and enable innovative aircraft component concepts by meeting multiple airframe or engine performance requirements simultaneously
- Develop high-fidelity, physics-based **models, computational methods, and simulation tools, together with benchmark validation tests** for airframe and engine materials and structural configurations



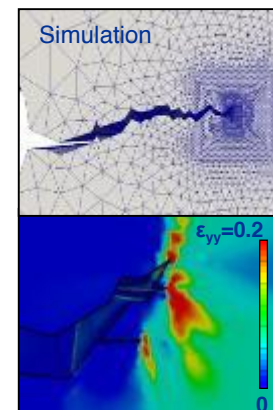
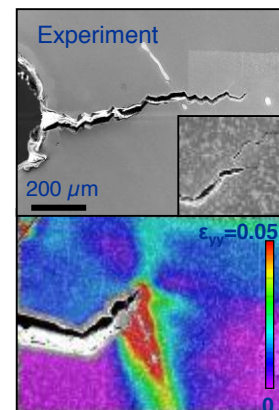
EBC-Coated CMC Vane



Advanced 3D Fiber Architecture



Shape-Memory Alloys



Computational Materials

## OBJECTIVE

Lightweight compact actuators based on shape memory alloys are enabling technology for certain aeronautic applications but no alloys have been developed with properties optimized for solid-state actuation.

## APPROACH

- Develop and mature portfolio of high-temperature shape memory alloys (HTSMA) based on two-phase microstructures.
- Demonstrate viability of new HTSMA for torsional actuation.
- Develop in-house test capability for determining torsional actuation behavior and durability.

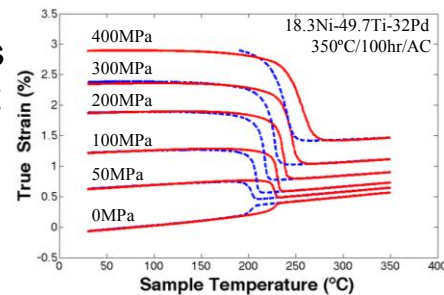
## SIGNIFICANCE

**Compact, lightweight, high-force, solid-state actuators will enable improved air vehicle designs.**

## FY15 ACCOMPLISHMENTS

- **Developed new NiTi22.3Hf and NiTi32Pd alloys for 200°C applications and above.**
- Developed in-house capability to make splined SMA torque tubes for UAV flight demonstration.
- Designed, developed, and built a series of torque tube testers (6 total).
- Published 22 peer-reviewed journal articles and TMs on SMA technology.

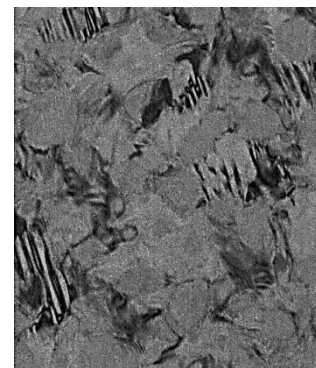
POC: Othmane Benafan (GRC)



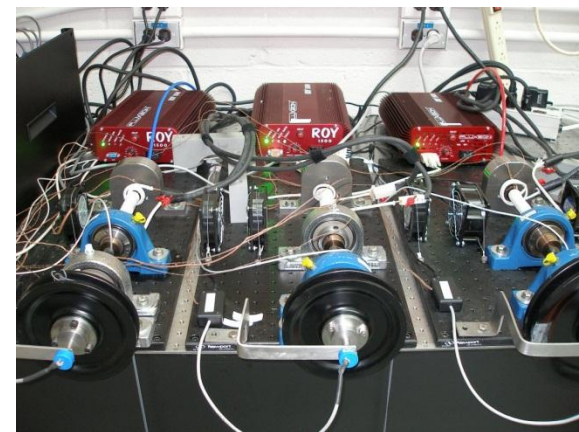
**New HTSMA for  
>200 °C operation**



**NiTiHf torque tube actuators  
for UAV flight demo**



**NiTi-32Pd HTSMA provides  
functional stability**



**Newly developed torque tube testers for  
HTSMA durability testing**





# Standardized SMA Test Methods for Aerospace Applications



## PROBLEM

- The absence of accepted standards for SMA material and actuator components is hindering progress towards production applications.
- Material strength properties must be based on enough tests of material meeting approved specifications to establish design values on a statistical basis.

## APPROACH

- Develop and release standardized test methods for Shape Memory Alloys (SMA) materials and actuator components for use in aerospace applications.
- Recommend test methods to regulatory agencies and standards bodies (e.g., ASTM).

## SIGNIFICANCE

This testing standards will be the first ever regulatory agency-accepted test standards for SMA actuation.

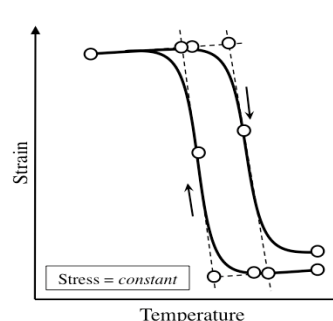
## FY15 MILESTONES/ACCOMPLISHMENTS

- Selection of two primary candidates for test standard development (Fig. 2). Preliminary standards drafting and assessment are in review
- Beginning engagement with Standards Development Organizations(SDO). Meeting with ASTM committee this fall 2015.
- Published a fast track communication article in the Smart Material and structures Journal (Vol. 24, 2015, 082001)

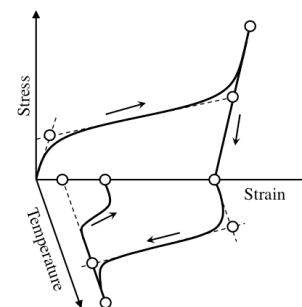
POC: Othmane Benafan (GRC)



Current members (in boxes) of the Aerospace Vehicle Systems Institute (AVSI), an international research cooperative bringing together leading aircraft manufacturers, suppliers, government organizations and research universities.



Constant Force Thermal Cycling



Tension/Compression Free Recovery

Initial Testing Specifications. First two uniaxial test methods correspond to the two most important behaviors exhibited by SMA materials when used as an actuator.



# 200C NiTi-22.3Hf Precipitate-Reinforced HTSMA



## PROBLEM

- No commercially viable alloys have been developed capable of solid-state actuation for use at temperatures beyond 200°C.
- Dimensional stability is typically a major issue.
- Small variations in composition can deflate the transformation temperature below what is desired.

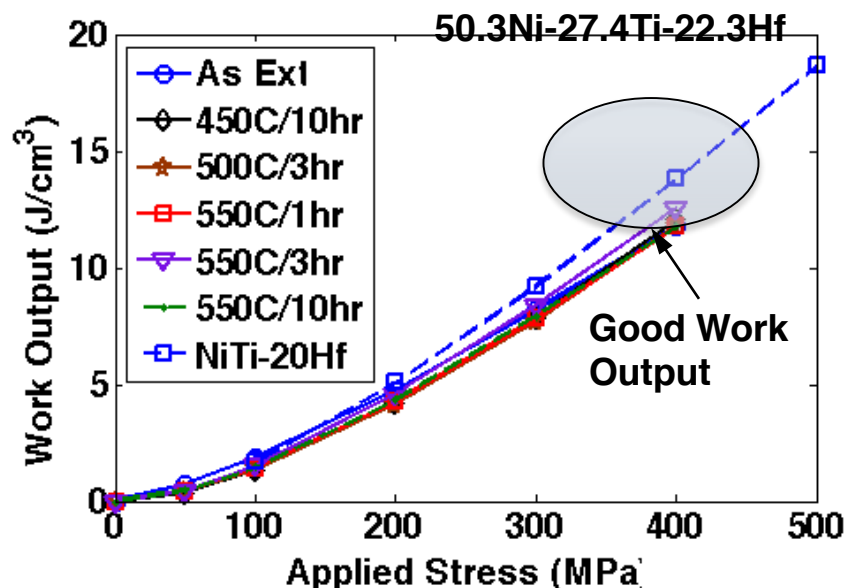
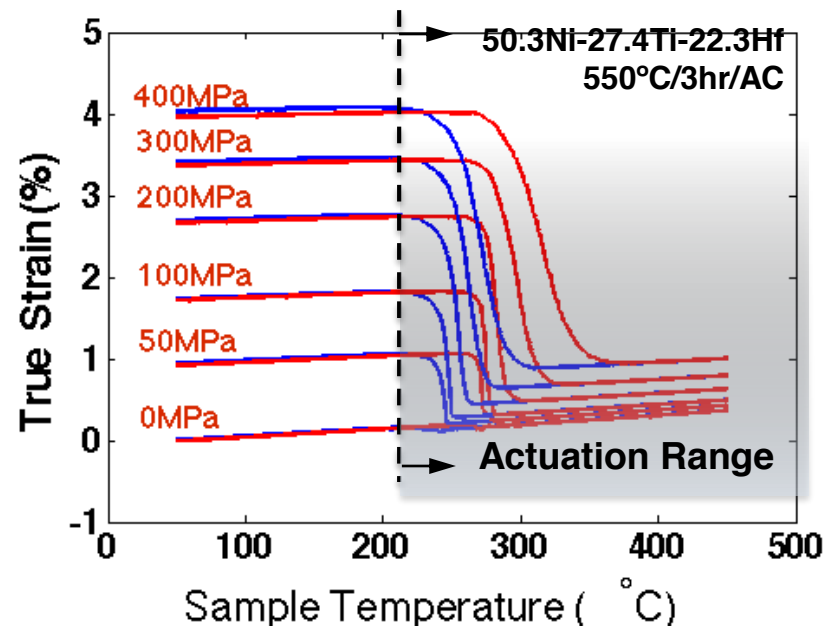
## OBJECTIVES

- Map out the broader range of compositions and heat treatment combinations that provide this 200°C capability.
- Produce NiTi-22.3Hf alloys with varying Ni contents and determine extent of stabilization and temperature recovery by heat treatments.

## SIGNIFICANCE

- Emerging applications in morphing airframe, hypersonic, and engine applications have a need for high temperature shape memory alloys with a 200 °C transformation temperature. Appropriate compositions and heat treatments identified in this work impart **excellent dimensional stability** and desired **increase in transformation temperatures**.
- These new 22.3 Hf alloy formulations provide a low cost alternative when compared to the high transforming alloys such as NiTi-Pt, Pd or Au alloys, thus providing a potential path for viable commercial scale up.

POC: Glen S. Bigelow, Ronald D. Noebe (GRC)



## PROBLEM

Ti-rich NiTiPd alloys exhibit high transformation temperatures, but poor dimensional stability. Ni-rich shape memory alloys often have much lower transformation temperatures, but heat treatment of Ni-rich NiTi based SMAs has been shown to improve transformation temperatures and dimensional stability through the formation of fine precipitates.

## APPROACH

- Identify a Ti-rich NiTiPd composition with appropriate transformation ( $A_F \sim 300^\circ\text{C}$ ).
- Melt and produce NiTi-32Pd alloys with varying Ti/Ni contents.
- Heat treat samples at various times/temperatures.
- Perform mechanical testing to determine extent of stabilization and temperature recovery by heat treatment.

## SIGNIFICANCE

- High temperature shape memory alloys are required for many possible applications. Dimensional stability is imperative for long cycle applications. Heat treated Ni-rich NiTiPd alloys can provide both high temperature and dimensional stability.

## FY15 MILESTONES/ACCOMPLISHMENTS

- NiTi-32Pd HTSMAs melted and extruded.
- Samples heat treated and load bias tested.
- Nano-scale precipitates formed through heat treatment.
- Transformation temperature of Ni-rich alloys improved by up to  $70^\circ\text{C}$  by heat treatment.
- Dimensional stability improved by a factor of 10 to 600 by alloying and heat treat.

POC: Glen S. Bigelow (GRC), Anita Garg (U. of Toledo)

